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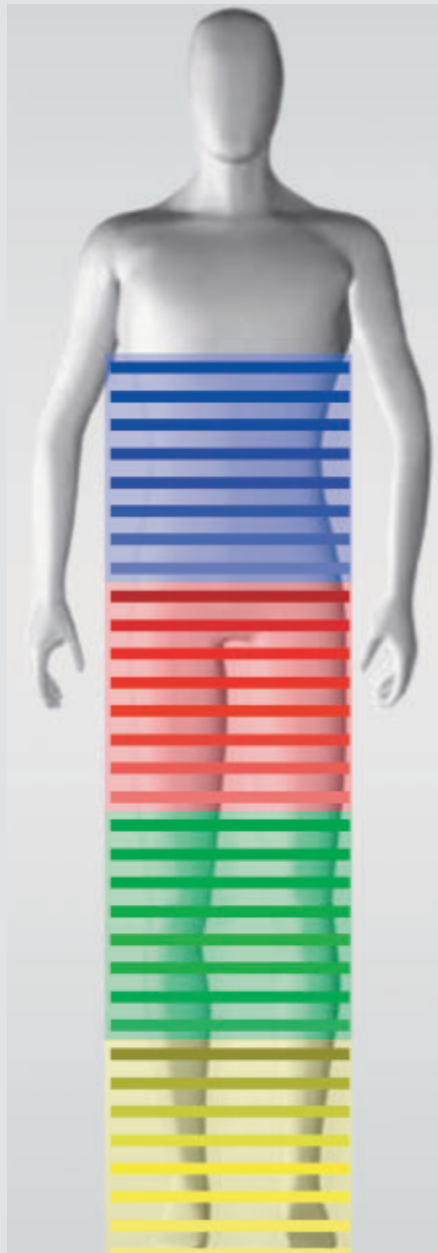
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Multiple Steps



Continuous Table move

SIEMENS
medical

syngo TimCT – Continuous Table Move, Powered by Tim

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Scanning with Continuous Table Move (CTM) is a very new and exciting technology for all applications that require large anatomical coverage, beyond the scanners intrinsic field-of-view (FoV). As publications show [1–30], CTM has so far been possible only on prototype scanners, with significant modifications to the MR system.

Siemens is proud to introduce *syngo* TimCT – Continuous Table move, powered by Tim (Total imaging matrix) for the new T-class generation of Tim systems. The following chapters will discuss the physical principles of Continuous Table Move, the benefits, the scanner requirements and the Siemens implementation of Continuous Table Move: *syngo* TimCT.

TimCT – Physical Principles

There are many possible methods for Continuous Table Move, the main differentiators being the readout direction (parallel or orthogonal to the direction of table movement) and the imaging method (2D or 3D). In the literature, we find examples of a large variety of methods, e.g.

1. 2D transversal sequential scans [19, 22, 26]
2. 2D transversal multi-slice scans [13, 15, 20, 21]
3. 3D transversal scans [16, 18, 23, 24, 27]
4. 2D and 3D radial transversal scans [3, 28]
5. 3D coronal scans [1, 2, 4–6, 8–12, 14, 17, 25, 29, 30]

In the following, we will concentrate on the methods 1 and 5 of this list since these are the first implementations of the new Siemens product, *syngo* TimCT.

Transversal 2D Sequential

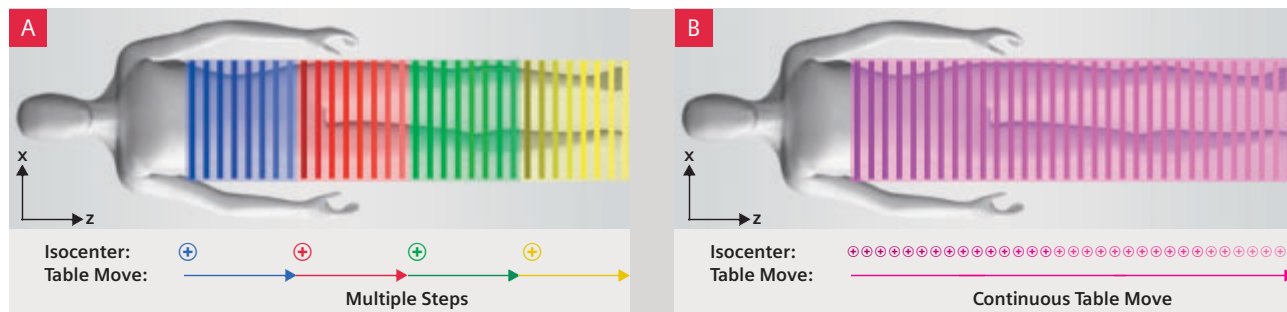
The transversal orientation is useful when one is interested in the whole extension of anatomy in both the left-right direction (x) and the anterior-posterior direction (y). The sequential mode makes sense with fast sequences (e.g., TurboFLASH, HASTE, single shot EPI) where the complete phase-encoding of the single slice can be applied without pauses.

With “Transversal 2D Sequential”, each slice, in axial orientation, is measured completely before proceeding to the next slice. The sequential method is different from conventional multi-slice scans (e.g., with Spin Scho) where a stack of slices is excited in an interleaved fashion.

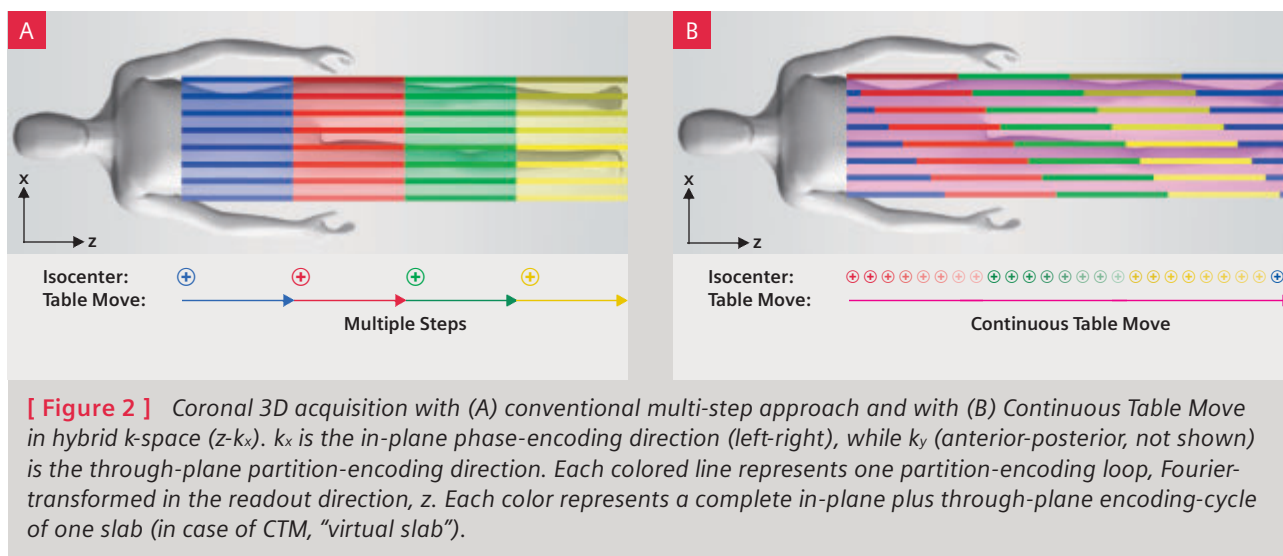
In conventional imaging, one would plan a stack of slices at isocenter, scan all these slices sequentially, move the table by a distance equaling the thickness of the slice stack, and repeat this process until the entire scan range is covered (Fig. 1A).

This approach has some disadvantages:

- a) The “outer” slices of the stack (indicated in Fig. 1 by the darker and brighter shades) are out of isocenter in a region of lower magnet homogeneity and lower gradient linearity, possibly degrading image quality.
- b) Scan efficiency is compromised since it is interrupted by table moves without scanning.
- c) Planning of the slice stacks is more cumbersome and time-consuming since each slice stack has to be planned exactly adjacent to its neighbors.



[Figure 1] Transversal 2D sequential scanning with (A) conventional multi-step approach and with (B) Continuous Table Move. Each colored line represents a transversal image.



[Figure 2] Coronal 3D acquisition with (A) conventional multi-step approach and with (B) Continuous Table Move in hybrid k -space (z - k_x). k_x is the in-plane phase-encoding direction (left-right), while k_y (anterior-posterior, not shown) is the through-plane partition-encoding direction. Each colored line represents one partition-encoding loop, Fourier-transformed in the readout direction, z . Each color represents a complete in-plane plus through-plane encoding-cycle of one slab (in case of CTM, “virtual slab”).

“Transversal 2D Sequential” is the most intuitive method when thinking about Continuous Table Move. Each slice is exactly scanned at isocenter (indicated by identical shades of purple of lines and isocenter symbols in Fig. 1B), while the table is constantly moving.

The table velocity for “Transversal 2D Sequential” with gap-less axial slices is the slice thickness divided by the scan time per slice:

$$V_{\text{Table}} = \frac{\text{Thk}_{\text{Slice}}}{N_{\text{Phase}} \cdot \text{TR}} = \frac{\text{Thk}_{\text{Slice}}}{\text{TA}}$$

Continuous Table Move with the “Transversal 2D Sequential” approach is advantageous in the following aspects:

- Each slice is scanned at isocenter, in a region of optimal magnet homogeneity and gradient linearity, optimizing image quality.
- Since no time is required for table movements while scanning is suspended, Continuous Table Move offers higher scan time efficiency.
- Workflow is also facilitated by the fact that the whole slice stack can be planned in one seamless block.

The method “Transversal 2D Sequential” is implemented in TimCT FastView, used for easy extended-FoV localizer imaging. It is based on a fast TurboFLASH sequence (refer to chapter “TimCT Product Implementation” for more details).

Coronal 3D

The coronal orientation is beneficial if the region of interest has a large extension in the cranio-caudal direction (z) and the left-right direction (x), but when it is not necessary to cover the whole anatomy in the anterior-posterior direction

(y). These conditions are exactly met by peripheral angiography, explaining the fact that most CTM publications about the “Coronal 3D” method cover this application.

The conventional approach to cover the entire peripheral vasculature is to acquire multiple coronal 3D slabs with overlapping regions (overlaps omitted in Fig. 2 for simplicity). Although this multi-step approach is well-established and yields very good results in clinical routine, there are a couple of intrinsic disadvantages:

- Scan efficiency is compromised since it is interrupted by table movements without scanning.
- Planning of the coronal slabs is more cumbersome and time-consuming since typically all slabs are aligned individually in order to seamlessly cover the whole peripheral vasculature with defined overlaps.
- The individual slabs have to be composed to get the complete vasculature in one resulting image (although this can be done automatically with the Inline Composer).
- The resulting composed image may suffer from “boundary artifacts”, i.e. shading or signal differences at the edges of the (previously) independent 3D slabs.

As with multi-step conventional imaging, there are also “subsets” of the total scan range with Continuous Table Move. Each subset represents one complete cycle of in-plane and through-plane phase-encoding, $N_x \times N_y$. We will call the extension of each subset in z -direction the “intrinsic FoV”, or FoV $_z$. FoV $_z$ is analogous to the FoV in the multi-step approach. Due to the continuous table movement, these subsets are “sheared” in hybrid k -space (z - k_x), see Fig. 2B. The echoes in z -direction are Fourier-transformed and combined. Fourier

transformations in the two remaining directions, x and y, will result in one single large FoV of the total scan range. This method, with the echo readout in z-direction, was first proposed by Kruger et al. in a publication from 2002 [1].

The maximum table velocity can be calculated by setting into relation (a) the time it takes to perform a complete encoding cycle $N_x \times N_y \times TR$ to (b) the time it takes to move the table by one FoVz. This yields:

$$V_{\text{table}} = \frac{\text{FoV}_z}{N_x \cdot N_y \cdot TR}$$

A table velocity smaller than this maximum value is analogous to an overlap of slabs in the conventional multi-step approach. It becomes clear from this formula that the intrinsic FoV in z-direction has an effect on the achievable table velocity V_{table} and/or spatial resolution $N_x \times N_y$.

“Coronal 3D” with Continuous Table Move offers some significant advantages compared to the multi-step approach:

- There are no scanning pauses for table moves, scan time efficiency is maximized.
- Planning is straight-forward, no more difficult than planning of a single stationary FoV: The total scan range can be flexibly increased or decreased in a continuous manner, not only in multiples of the intrinsic z-FoV.
- The total scan range is one single entity – it is “intrinsically composed”.
- The smooth scanning process will result in less boundary artifacts.

The method “Coronal 3D” is implemented in TimCT Angiography, based on a fast 3D FLASH sequence (refer to chapter “TimCT Product Implementation” for more details).

Benefits of syngo TimCT

When scanning a large scan range, Continuous Table Move (CTM) has many advantages compared to multi-step approaches:

Workflow

Fast workflow is probably the biggest advantage of CTM:

Easier and faster examination prescription: The setup of the examination is extremely easy. With an integrated implementation like TimCT, it is no more complicated than, for example, a conventional stationary head scan.

Reduced post-processing: Multi-step approaches can require extensive post-processing [30]. With CTM, the anatomy of the whole scan range – or any part of it in detail – can be viewed directly, without the need of any composing processing.

TimCT also supports Inline multiplanar reconstruction (MPR),

Inline Subtraction and Inline maximum intensity projection (MIP): Processing is done automatically at the end of the scan, without any user interaction.

Speed

CTM has higher scan time efficiency than multi-step approaches because there are no scanning pauses during table motion. [1, 2, 17] The higher scan time efficiency is especially beneficial for contrast-enhanced MR angiography where short scan times are dictated by physiology, i.e. blood velocity.

Certain sequence techniques require dummy RF pulses in the beginning to achieve a steady state. With multi-step approaches, these need to be repeated at every level [1, 2] – which is not necessary with CTM.

Image Quality

With CTM, scans are always done exactly at isocenter, i.e. in the region of maximum homogeneity. This directly translates into improved image quality.

Especially ultrashort magnets with lower homogeneity can benefit from CTM. Continuous Table Move can significantly facilitate large-coverage scans with ultrashort magnets. [21, 22, 27]

Being intrinsically continuous, CTM provides seamless images, without the boundary artifacts that are sometimes visible in composed multi-step images. [1, 2]

Patient Comfort

A CTM scan is a smooth process without repeated scan-move-stop procedures. The less frequent “table jerking” increases patient comfort. [9]

Be Ready for the Future

syngo TimCT – Continuous Table move, powered by Tim – offers CT-like scanning with MR. And like Spiral CT, TimCT offers a huge potential. Tremendous improvements for many applications are already visible on the horizon, e.g. interactive or even automatic adaptation of table velocity, controlled by bolus speed [8, 29]; simultaneous acquisition of multiple contrasts in one table stroke [15]; combination of Continuous Table Move with dynamic imaging [4, 5, 7]; tumor staging [19] – to name just a few.

MR – CT Analogies

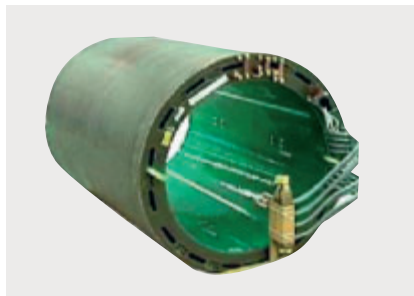
Although magnetic resonance imaging (MRI) and computed tomography (CT) are fundamentally different in the way the images are generated, there are some striking analogies in the historical development of both modalities.



MR in the 80s – The Decade of Magnets

One could call the 80s the “decade of magnets”. The main topic at that time was the question for the optimal field strength – 0.5T, 1T or 1.5T. MR systems at that time had only one RF channel and slow gradients.

The CT analogy at that time was the question for the best detector material, gas or solid state. CT scanners in the 80s had slow rotation times and only one detector ring.



MR in the 90s – The Decade of Gradients

Gradient performance was the most critical question in the 90s. Both gradient amplitude and slew rate were increased by orders of magnitude, up to the limit where gradient performance is no longer limited by technology, but by the patient’s peripheral nerve stimulation limit.

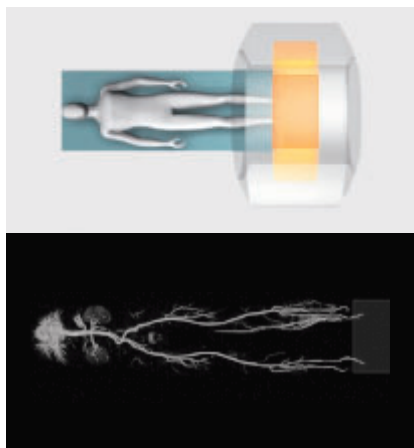
At the same time, CT saw an increase in rotation speed, up to more than 3 rotations per second.



MR in the 2000s – The Decade of RF

RF technology and Parallel Imaging have been the primary focus in this decade, with an increase of the number of RF channels and the development of “high-density” coils. Siemens introduced Integrated Panoramic Array (IPA) as early as 1997, and Tim (Total imaging matrix) technology in 2003, with up to 102 seamlessly integrated coil elements and up to 32 truly independent RF channels. There is even a prototype with 128 RF channels. Tim offers high flexibility, accuracy and speed, with high PAT factors in all body regions and all directions.

The CT analogy to RF technology is multi-detector technology, also offering larger coverage in less time, with higher image quality and spatial resolution.



MR in 2006 – TimCT

Now, in 2006, Siemens pioneers TimCT – Continuous Table move, powered by Tim. Peripheral run-off studies can be done faster, and TimCT tremendously facilitates the workflow. The potential of TimCT for peripheral angiography and for other applications is huge.

MR’s TimCT is very similar to CT’s spiral technology. Both technologies enable seamless scanning – with high speed and ease of use.

Actually, spiral CT scanners have been available for more than 15 years. One might take this as a proof point that it was about time that MR caught up with CT in this technological perspective. Actually we expect that MR systems without TimCT capabilities will be similarly shunned in a few years as CT scanners without spiral capabilities would be today.

Requirements for syngo TimCT

Scanning with Continuous Table Move (in analogy to Spiral CT) and not wasting time for multiple Scan–Stop–Adjust procedures sounds straight-forward and easy. However, it is not trivial. The MR system has to meet numerous requirements to make TimCT possible. Here is a list of all the technical requirements and how these are met by syngo TimCT.

Table Requirements	
<p>■ Shielded table drive</p> <p>The electronics of the patient table need to be shielded. An unshielded table would result in electronic interferences and consequently image artifacts.</p>	<p>syngo TimCT ✓</p> <p>Actually, the patient tables of all Tim systems are shielded. Siemens had the vision of TimCT years ago and prepared the scanners accordingly – which made it much easier to implement TimCT and makes it easier to upgrade to TimCT, too.</p>
<p>■ Software-enabled table motion</p> <p>For routine clinical use, manual table motion is of course no alternative. It is imperative that the table can be moved from the console, easily and flexibly. The remote table move capabilities need to cover the whole scanning distance.</p>	<p>syngo TimCT ✓</p> <p>Software-enabled table motion is standard with all Tim systems. One major aspect here is that the cables of the Tim coils are very short and – unique to Siemens – plug into the table, thus reducing the risk that the cables get jammed during the table move.</p>
<p>■ Control of table speed with high accuracy</p> <p>For sub-millimeter image resolution, the accuracy of the patient table has to be accordingly high. Furthermore, software-controlled sub-pixel correction has to be implemented. [1]</p>	<p>syngo TimCT ✓</p> <p>All Tim systems feature an accurate control of table speed and position. In addition, a sub-pixel software correction is implemented with TimCT.</p>
Software Requirements	
<p>■ Sequences</p> <p>Imaging sequences supporting Continuous Table Move are required.</p>	<p>syngo TimCT ✓</p> <p>TimCT FastView and TimCT Angiography are available with the new T-class generation of scanners (software syngo MR B15). The flexible architecture of IDEA, our sequence programming tool, facilitates the development of TimCT sequences.</p>
<p>■ Image processing</p> <p>The measured raw data need to be corrected, processed and displayed automatically in order to guarantee a smooth workflow.</p>	<p>syngo TimCT ✓</p> <p>With TimCT, image processing is fully integrated, including corrections (see below), fully automated image reconstruction of the full FoV, Inline MPR, and Inline Subtraction & Inline MIP for angiography.</p>
<p>■ Graphical slice positioning</p> <p>Beyond the “standard” capabilities, graphical slice positioning needs to offer specific features, e.g. independent control of intrinsic FoV and total scan range, control of active coil elements etc.</p>	<p>syngo TimCT ✓</p> <p>With the Tim Planning Suite, we were already prepared for most aspects of TimCT graphical slice positioning. With T-class, an intuitive (color-based) control of intrinsic FoV and total scan range has been added.</p>

Software Requirements

■ Adjustments

Frequency, transmitter and receiver adjustments must be available over the whole scan range.

syngo TimCT ✓

Frequency and transmitter adjustments are performed in a short TimCT Adjustment scan, also during table motion. A time-consuming receiver adjustment is in general not required with all Tim systems, due to the large dynamic range of the receiver.

Image Quality Requirements

■ High SNR and high spatial resolution

The requirements for optimal diagnostic quality can only be met with surface coils. In comparison to an integrated body coil, surface coils offer 2-4 times more signal-to-noise ratio (SNR).

The benefit of surface coils has often been mentioned in the literature [5, 8, 16, 17, 29].

syngo TimCT ✓

With his readily available Matrix coils, Tim is the ideal basis for TimCT.

The “high-density” Matrix coils offer highest SNR in all body regions which can easily be translated into high spatial resolution and short scan times.

■ Gradient non-linearity correction

It is known from the literature that gradient non-linearity correction is basically a must for Continuous Table Move scanning.

Without this correction, the lateral anatomy would become blurry – the farther outside of isocenter, the worse [6, 25].

syngo TimCT ✓

Inline gradient non-linearity correction is fully integrated into TimCT and automatically performed.

■ Phase correction

A phase correction in the readout direction is required for coronal scans, in order to avoid a shading pattern in the reconstructed images [11].

syngo TimCT ✓

Phase correction is fully implemented with TimCT Angio-graphy.

Speed Requirements

■ Parallel Imaging

Parallel Acquisition Techniques (PAT) have become accepted for the majority of applications. PAT is an *essential* tool for higher speed.

Especially for peripheral angiography, short scan times (to follow the contrast bolus) combined with high spatial resolution (to be able to diagnose also small vessels and pathologies) are critical [30].

syngo TimCT ✓

Again it comes back to Tim, with “high-density” coils in all body regions, enabling Parallel Acquisition Techniques (PAT) in all directions. TimCT is compatible with iPAT using Tim’s unique Matrix coil design.

Note that Parallel Imaging can *only* be performed with surface coils, not with an integrated body coil. See section “Coil Technology Requirements” below.

■ Calibration for Parallel Imaging

Coil calibration for Parallel Imaging needs to be possible with a continuously moving table.

Many implementations today rely on separate calibration scans that are not integrated into the scan. A large number of these calibration scans would be necessary to cover the whole scan range which would result in very long examination times and low productivity.

syngo TimCT ✓

The Auto-Calibration algorithm, standard with Siemens iPAT (integrated Parallel Acquisition Techniques), is the ideal solution for Parallel Imaging with Continuous Table Move.

The benefits of Auto-Calibration are covered in [30].

Coil Technology Requirements	
<p>■ Connection of multiple coils Given the fact that good diagnostic image quality can only be achieved with surface coils, it needs to be possible to connect all surface coils simultaneously for full anatomical coverage.</p>	<p><i>syngo TimCT</i> ✓ Beside having a “high density” of coil elements for optimal image quality, one of the major benefits of Tim is the possibility to simultaneously connect up to 10 coils, with up to 102/76 (3T/1.5T) seamlessly integrated coil elements.</p>
<p>■ Flexible coil combinations For flexible coverage of arbitrary regions-of-interest, coil combinations are required.</p>	<p><i>syngo TimCT</i> ✓ With Tim all Matrix coils can be combined for seamless anatomical coverage. Elements from different coils can be used simultaneously.</p>
<p>■ Surface coils plug into patient table With multiple coils being connected for large anatomical coverage, coil cables need to be short and integrated into the table. Long coil cables (e.g. attached to the magnet front) create safety issues during table movement.</p>	<p><i>syngo TimCT</i> ✓ All Matrix coils have very short coil cables that directly plug into the patient table.</p>
<p>■ Automatic coil detection With a large scan range being covered by multiple coils, it would be extremely cumbersome and time-consuming if the user had to “teach” the system the exact location of each coil element. Therefore, the exact position of each coil has to be detected automatically.</p>	<p><i>syngo TimCT</i> ✓ All Tim systems feature AutoCoilDetect. All coil elements are automatically detected in the localizer scan and depicted in the graphical slice positioning.</p>
<p>■ Dynamic coil switching Beyond the detection of the coils, it is also necessary to automatically activate and de-activate the coil elements during Continuous Table Move. It would be next to impossible to manually pre-select the coil switching for a continuous scan during table motion. For a discussion of the benefits of dynamic coil switching see [30].</p>	<p><i>syngo TimCT</i> ✓ With AutoCoilDetect (see above), the Tim systems were already prepared for the next step, AutoCoilSelect. Now, the user does not need to take care of coil selections at all, boosting workflow and robustness – and being one of the major revolutionary features that make TimCT possible.</p>
Patient Safety Requirements	
<p>■ SAR monitor SAR values need to be known for all body locations.</p>	<p><i>syngo TimCT</i> ✓ SAR is checked for the whole scan range in a short TimCT Adjustment scan.</p>

In summary

As the literature about Continuous Table Move (CTM) shows, only a few sites worldwide have been working on CTM. The reason for this is the long list of very challenging technical requirements for Continuous Table Move. All CTM sites so far have been pure prototype installations that have to cope with limitations including a) external con-

trol for table motion, b) external image processing, c) scans with the body coil only, no surface coils, and d) no Parallel Acquisition Techniques. With Tim, Siemens has the ideal platform for the implementation of TimCT. This is expressed with “*syngo TimCT – powered by Tim*”.

syngo TimCT Product Implementation

syngo TimCT FastView

TimCT FastView is an extremely fast localizer sequence. It is based on a sequential TurboFLASH sequence, i.e. all slices are acquired in a sequential mode. Each slice is scanned at isocenter while the table is moving. The slice orientation is axial.

The rather coarse spatial resolution allows very fast scanning, with a table velocity as high as 5 cm/sec – e.g., 150 cm can be covered in just 30 seconds.

Benefits of TimCT FastView:

- Inline Technology is implemented: With Inline MPR, sagittal and coronal reformats are automatically generated on the fly.
- TimCT FastView can be immediately performed without any adjustments. SAR (specific absorption rate) is extremely low since only small flip angles are used. TimCT FastView is done with the integrated body coil and can be done independently of any coil used for the specific examination.
- TimCT FastView can even be initiated without laser light positioning, using a preset (user-definable) scan range that e.g. covers the whole spine. This has the potential to increase productivity due to shorter patient setup times.

TimCT FastView is standard with all T-class systems.

syngo TimCT Angiography

TimCT Angiography is optimized for contrast-enhanced peripheral run-off studies in coronal (or sagittal) orientation. It is a high-resolution 3D sequence. TimCT Angiography has the full flexibility of all parameters, as in a “conventional” scan. Additionally, the total scan range can be flexibly increased beyond the intrinsic FoV of the scanner.

Benefits of TimCT Angiography:

- Workflow is facilitated since the whole process is completely automated. The setup of the scan is easier than a conventional multi-step approach, planning steps are reduced by up to 50%. Inline Subtraction and Inline MIP, all automatically processed with Inline Technology, further increase the examination speed.
- TimCT Angiography offers maximum scan time efficiency – no scan interrupts during table move phases as in conventional multi-step approaches. Consequently, the contrast bolus can be tracked faster and/or with higher spatial resolution.
- Tim technology, AutoCoilDetect and AutoCoilSelect, all exclusive to Siemens, make it possible to perform TimCT Angiography with optimal image quality, i.e. with a signal-to-noise ratio that can only be achieved with surface coils.

TimCT Angiography is an option for all T-class systems.

syngo TimCT Adjustments

The TimCT Adjustments cover all adjustments that are required to run a TimCT scan with optimal image quality, fast workflow and full patient safety.

The TimCT Adjustments include Frequency Adjustment, Transmitter Adjustments, SAR Monitoring, AutoCoilDetect and AutoCoilSelect for all locations of the whole scan range. The adjusted values are then dynamically applied to the TimCT measurement on the fly. All connected coils are automatically detected during the TimCT Adjustments and then automatically selected during the TimCT measurement.

TimCT FastView does not require adjustments (see above).

The TimCT Adjustments can be run in combination with TimCT FastView (prior to TimCT Angiography), or they will be automatically performed with TimCT Angiography if they have not been done before.

The TimCT Adjustments are very fast and are performed with a table velocity of 5 cm/sec.

Prerequisites

T-class and syngo TimCT are available for

- MAGNETOM Trio, A Tim system
- MAGNETOM Avanto
- MAGNETOM Espree
- MAGNETOM Symphony, A Tim system

syngo TimCT is exclusive to the new generation T-class systems, introduced at the RSNA 2006. All Tim systems are upgradable to T-class.

syngo TimCT is compatible with 18 and 32 RF channels, i.e. Tim [76x18] and Tim [76x32] for 1.5T systems, and Tim [102x18] and Tim [102x32] for 3T.

The maximum scan range of all Tim systems is sufficient for a complete peripheral run-off study, i.e. from the renal arteries to the feet. Whole-body coverage is possible with the Telescopic Table which is part of the Tim Whole-Body Suite (optional).

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syngo TimCT – a Novel Concept for Whole-Body MRI

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Introduction

The application of whole-body MRI for staging of malignant diseases is increasingly accepted by clinicians. Results underlining the diagnostic significance of the procedure are encouraging [1, 2]. Parallel imaging (iPAT), multiple Matrix coils and receiver channels (Total imaging matrix, Tim) opened the door for high-resolution whole-body MRI. The work of Fautz and Kannengiesser [3] formed the basis of the current clinical applications of the novel technique termed TimCT, which utilizes continuously moving table acquisition to generate images of excellent diagnostic quality. Thus, an extended volume coverage is now possible within one examination in order to gain information from organ systems distant from the primary region of interest to complete one-step staging or to significantly reduce examination time. Currently, we routinely perform TimCT for rectal cancer staging and follow-up of patients with Crohn's disease.

Technique

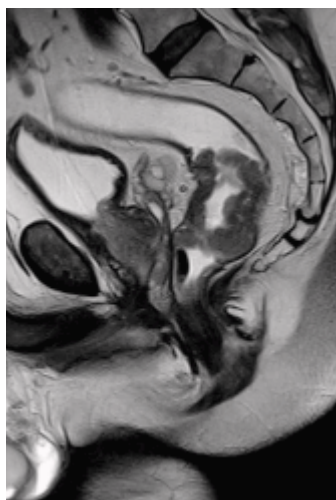
The purpose of Continuous Table Move MRI is to extend the field-of-view (FoV) in axial direction beyond the scanner's available scan region with a temporally and spatially seam-

less acquisition. The sliding multislice technique (SMS) was introduced in 2006 by Fautz et al. to minimize the required axial FoV without compromising image quality. The SMS uses a segmented multi-slice acquisition pattern, which samples the same phase-encoding step of any anatomical slice at the same spatial position in the scanner's axial FoV. The implementation of this special pattern avoids discontinuities between the images along the slice axis, for example, gradient non-linearity, because all z-dependent scan properties are encoded identically for all slices. The full k-space data of any slice is collected while the slice moves through the scanner from one scan position to the next (Continuous Table Move, CTM). The simultaneous acquisition of multiple slices is possible by just shifting the acquisition trajectories of different slices in time.

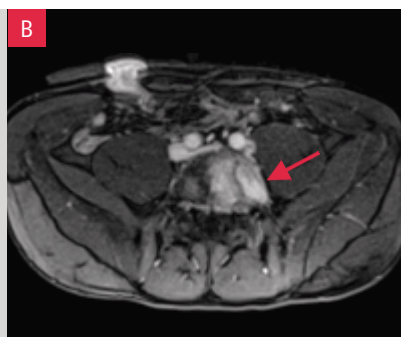
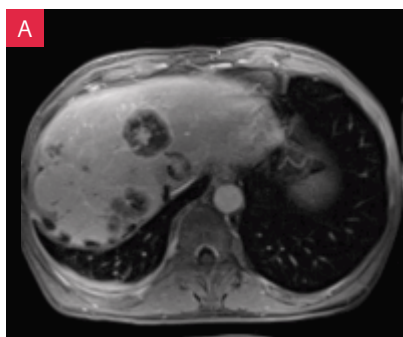
SMS implemented in the TimCT product can be applied to single-shot sequences (like FLASH) as well as to multi-shot sequences (like TSE). We now routinely perform a T1-weighted contrast-enhanced FLASH sequence with an initial breath-hold phase of 20 s to ensure artifact-free imaging of the liver and a free-breathing TIRM sequence. For both sequences the table speed is set to 1 cm per second. The sequence parameters are summarized in Table 1.

Clinical applications

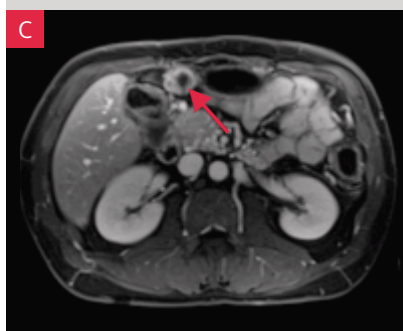
High-resolution pelvic MRI represents the current gold standard of local staging of rectal cancer [4]. No other state-of-the-art imaging modality has the ability to directly visualize the relationship between tumor and resection margin. To overcome step-by-step staging of rectal cancer patients using different imaging modalities, we integrated TimCT into a high-resolution imaging protocol for initial work-up and surveillance. With TimCT we perform both, an axial breath-hold contrast-enhanced T1-weighted FLASH sequence in a portal dominant phase to detect liver metastases and retroperitoneal lymph nodes, and an axial free-breathing TIRM sequence to cover the lungs, whole abdomen and pelvis to depict lung



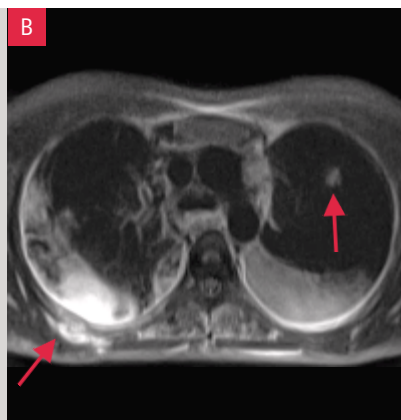
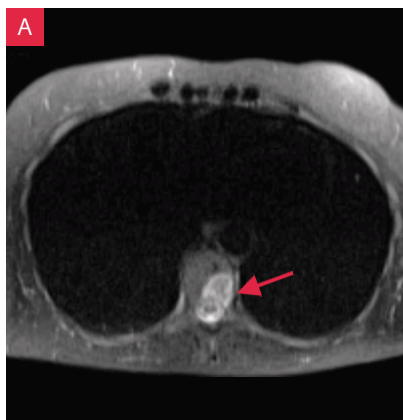
[Figure 1]
Example of T3 rectal cancer depicted on a sagittal T2-weighted TSE from our high-resolution pelvic MRI protocol.



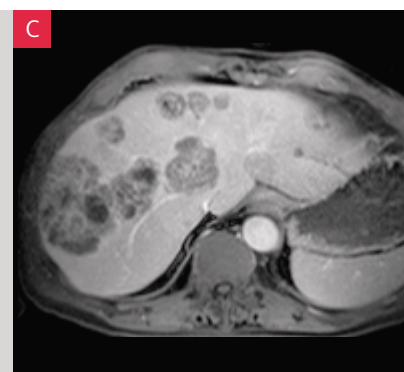
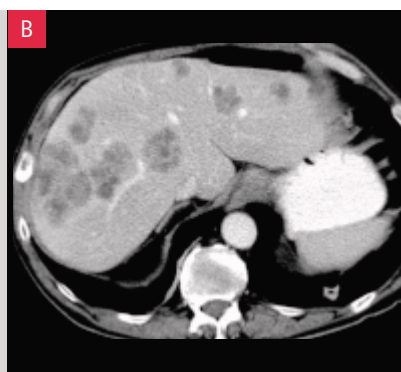
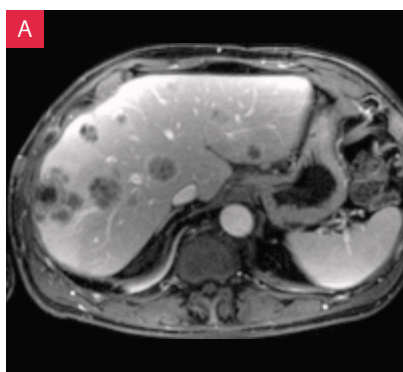
[Figure 2] Axial TimCT FLASH images clearly visualize hepatic metastases (A), a bone metastasis in the 5th lumbar vertebra (B).



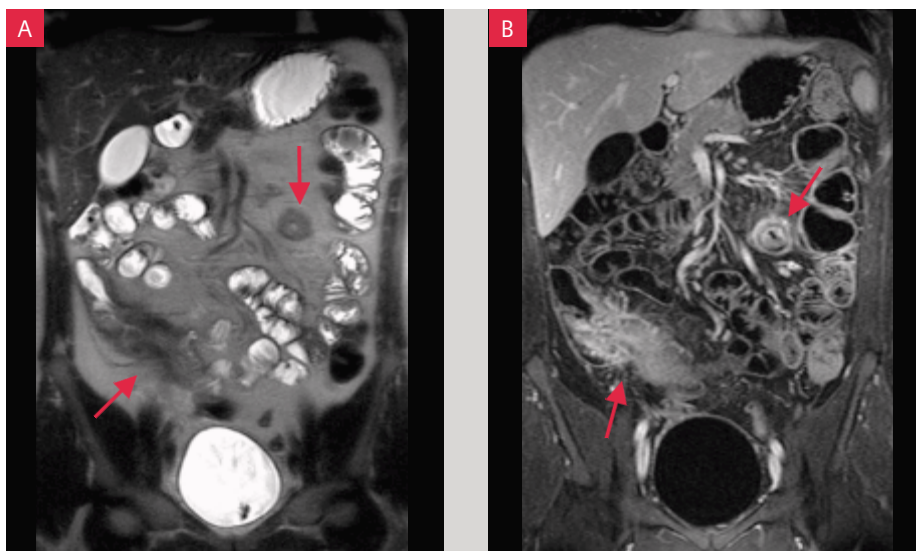
Lymph node involvement in the transverse mesocolon (C) and the hepatoduodenal ligament (D).



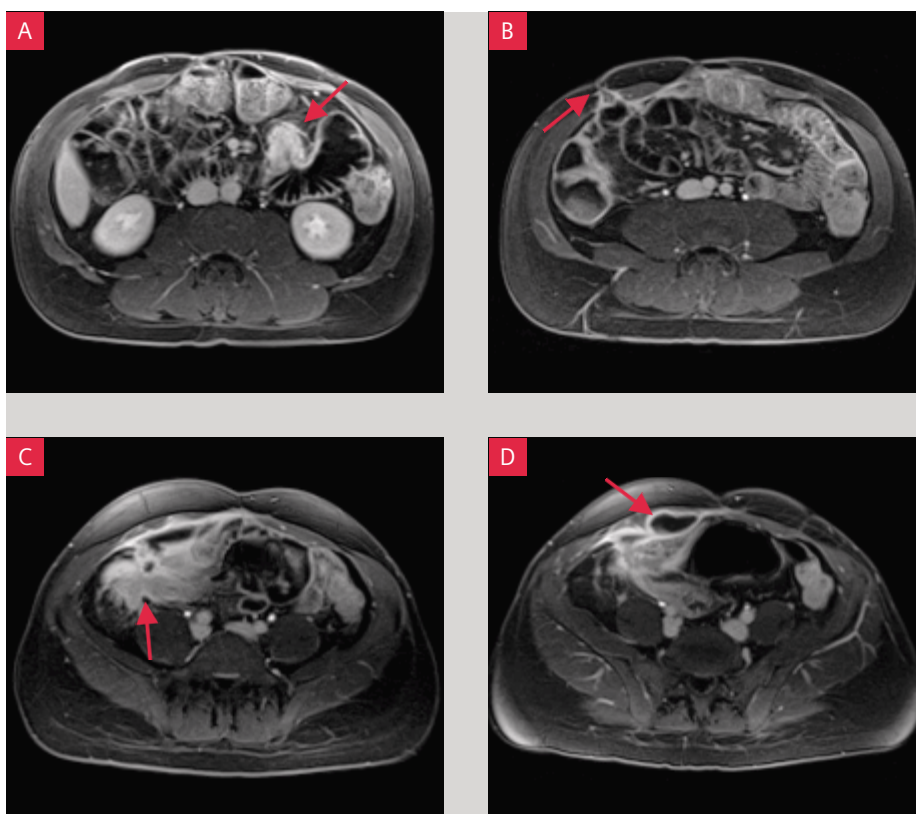
[Figure 3] Axial TimCT TIRM images demonstrating metastasis in the thoracic spine (A), lung metastasis, rib metastasis and malignant pleural effusion (B) in patients with rectal cancer.



[Figure 4] The comparison between (A) TimCT FLASH, (B) multi-slice CT and (C) conventional FLASH show the excellent lesion detection in this patient with recurrent rectal cancer and multiple metastases.



[Figure 5] Coronal HASTE (A) and contrast-enhanced VIBE (B) images derived from our Hydro-MRI protocol show manifestations of Crohn's disease with an inflammatory conglomerate and a skip lesion at the level of the proximal jejunum.



[Figure 6] Axial TimCT FLASH images of the same patient clearly demonstrate the skip lesion (A), an entero-cutaneous fistula (B).

The inflammatory conglomerate (C) and an abscess in the rectus abdominis muscle (D).

lesions, lymph nodes and bone marrow infiltration. Our experiences with TimCT for staging of rectal cancer patients are promising. The image quality has turned out to be comparable to that of a stationary upper abdomen protocol. Moreover, no differences in lesion detectability were found between TimCT and multi-slice CT (MSCT) regarding liver metastases and malignant lymph nodes.

MR-Enteroclysis is an established imaging technique for the evaluation of Crohn's disease since the degree of disease activity, presence of bowel wall pathology and extraintestinal manifestations of the disease (e.g. abscesses, fistulas) are accurately assessed [5]. For patient follow-up, Hydro-MRI is recommended by several working groups. Simplification and acceleration of the imaging protocol is of special interest, as

Crohn patients require repeated MRI during the course of the disease. However, the integration of Continuous Table Move MRI into a Hydro-MRI protocol for the evaluation of Crohn's disease has so far not been described. Our experiences with TimCT for the evaluation of patients with Crohn's disease are encouraging. The diagnostic sensitivity was found to be excellent compared to conventional axial multi-stage breath-hold sequences. Additionally, a marked reduction in total examination time can be achieved if TimCT is used.

Conclusion

syngo TimCT seems to be a promising adjunct to both rectal cancer staging and Hydro-MRI for follow-up of patients with known Crohn's disease. Scan efficiency and image quality are attributes of this upcoming technique. Furthermore, this new imaging modality is applicable to short-bore scanners like MAGNETOM Espree. In our opinion TimCT represents the next milestone in the evolution of whole-body MRI.



Prof. M. Langer, M.D. (left), O. Schaefer, M.D. (right)

Table 1: Sequence parameters for syngo TimCT

	TimCT-FLASH	TimCT-TIRM
TR	102 ms	3568 ms
TE	2.03 ms	101.22 ms
Slice thickness	5.0 mm	6.0 mm
Matrix	320 x 224	320 x 200
FoV	350 x 263 mm	400 x 250 mm
Pixel bandwidth	300 Hz/pixel	445 Hz/pixel
Flip angle	70°	60°
Slices/package	17	8
No. of packages	5	16
Pixel size	1.4 x 1.1 x 5.0 mm	1.6 x 1.1 x 6.0 mm
Parallel imaging	GRAPPA, factor 2	
Acquisition time	1 min.	4 min.

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MRI on the Move: syngo TimCT

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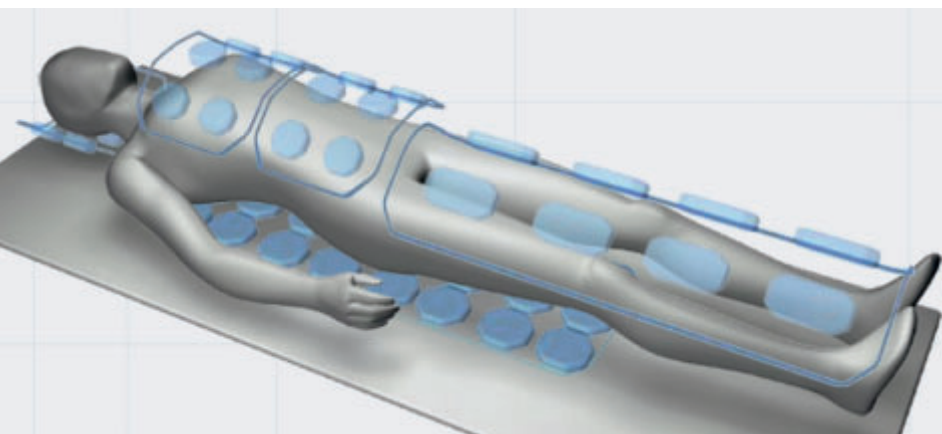
Introduction

The limited field-of-view (FoV) in the cranio-caudal direction inherent to conventional magnetic resonance imaging (MRI) has restricted this imaging modality to a single body region for almost two decades. Many diseases including atherosclerosis and malignant tumors, however, are not limited to a single body region. To fulfill the clinical needs, multi-station protocols using standard hardware [1–4] or commercially available rolling table platforms [5–7] have been developed to extend the FoV in the z-direction. Within the last five years, the combination of fast gradients, rapid automatic table motion and the Tim (Total imaging matrix) radiofrequency (RF) receiver coil technology has even opened the possibility for whole-body MRI without sacrificing signal-to-noise ratio (SNR) or spatial resolution.

These technical developments were the prerequisites to render MR angiography (MRA) one of the most exciting success stories in diagnostic radiology. Bolus-chase techniques employing multi-station table motion allow for the stepwise assessment of different vascular territories within a single examination. Although various multi-station approaches have shown to be effective, these protocols have inherent limitations: in order to cover extended anatomy with high image resolution and to stay within the arterial time window to avoid venous overlay, scan time must be as short as possible. Repositioning of the table between discrete stations

reduces the scan time efficiency due to interruption of data acquisition during this process. Additionally, gradient nonlinearities at the edges of individual fields-of-view have to be taken into account.

Most of these limitations have been eliminated by the introduction of the concept of continuously moving table data acquisitions providing seamless volume coverage and optimized scan time efficiency [8]. Since its application to 3D contrast-enhanced MR angiography of the peripheral arteries, several different acquisition and reconstruction methods for MR angiography during continuous table movement have been developed [8, 9]. In all these studies, the feasibility of such “move-during-scan” 3D MRA techniques has been demonstrated using the body radiofrequency (RF) coil for signal reception. The recent combination of the continuously moving table acquisition with full-body surface RF receiver coil coverage provided by the Tim Matrix coil technology allows exploring the full diagnostic potential of this technique [10]. The newest fully integrated implementation syngo TimCT (Continuous Table) reflects a revolutionary approach to MRI: motion during scanning, which was considered to be one of the major obstacles limiting the use of MR scanning, is used to extend coverage. TimCT provides seamless volume coverage and optimized scan time efficiency and is fully integrated into the Siemens system architecture. The first application



[Figure 1] Schematic of Tim phased-array Matrix coils used for peripheral MRA with the syngo TimCT technique. For peripheral MRA the patient lies on the build-in 24-channel Spine Matrix coil and is covered by two 6-element Body Matrix coils as well as by the 8-element Peripheral Angiography Matrix coil. This receiver coil setup ensures optimized signal detection and thus high signal-to-noise (SNR) over the target imaging region and additionally allows for the use of parallel imaging.

syngo TimCT Angiography is now available and will change the way to perform MRA examinations. Furthermore, techniques to collect stacks of axial 2D slices with different image contrasts during continuous table movement are currently

under development. The TimCT technique thus has the potential to further expand the role of MRI with all conceivable imaging applications that exceed the constraints of conventional fields-of-view.

Peripheral MRA workflow: Multi-station vs. syngo TimCT

Both peripheral MRA techniques – multi-station as well as TimCT – build on identical hardware prerequisites: full body coverage with dedicated multi-element phased-array surface coils (Tim – Total imaging matrix), connecting to a large number (32) of individual RF receiver channels, in combination with a long distance range of automatic table movement. For peripheral MRA the patient lies on the built-in 24-channel Spine Matrix coil and for anterior signal detection is covered

by two 6-element Body Matrix coils as well as by the 8-element Peripheral Angiography Matrix coil (Fig. 1). The Tim surface RF coils ensure optimized signal detection and thus high SNR over the target imaging region and additionally allow for the use of parallel imaging with GRAPPA (Generalized Autocalibrating Partially Parallel Acquisitions) [11] to either speed up data acquisition time or to increase spatial resolution instead.

Multi-station MRA

While acquisition of 3D peripheral MRA data sets with the conventional multi-station MRA protocol requires a relative large number of examination steps, the continuously moving table technique TimCT considerably eases the workflow (Fig. 2). Multi-station MRA of the peripheral arteries commences with centering the patient with the feet in the isocenter of the magnet (step 1), followed by the acquisition of TrueFISP localizers in three individual stations covering the pelvis, upper legs, and lower legs (steps 2–4). This is also associated with table movement between the stations while data acquisition is paused. Acquisition of TrueFISP localizers is subsequently followed by planning and acquisition of native scans

for the 3D FLASH (Fast Low-Angle Shot) MRA in coronal orientation on the individual localizers (steps 5–7). Following injection of the contrast agent (step 8), the CareBolus technique (step 9) provides information upon arrival of the contrast bolus in the target vascular region. Once the arriving contrast bolus enhances the signal in the images of the CareBolus sequence, data acquisition for the contrast-enhanced 3D FLASH MRA in the pelvis station is initiated (step 10). Data acquisition is being paused while the patient table moves to the upper leg station (step 11) and then – in another step – further down to the lower leg station (step 12).

Multi-station protocol		syngo TimCT protocol	
1	Position 230mm above feet	1	Fastview
2	📍 I_trufisp_feet	2	👤👤 TestBolus_tra
3	📍 II_trufisp_legs	3	👤 Vesselscout
4	📍 III_trufisp_abdomen	4	👤👤 Angio_pre_1300mm
5	👤 I_fl3d-cor_feet_pre	5	inject
6	👤 II_fl3d-cor_legs_pre	6	👤👤 Angio_post_1300mm
7	👤👤 III_fl3d-cor_abdomen_pre		
8	👤👤 inject gad		
9	👤👤 II_care_bolus_cor		
10	👤👤 III_fl3d-cor_abdomen_post		
11	👤👤 II_fl3d-cor_legs_post		
12	👤👤 I_fl3d-cor_feet_post		

[Figure 2] Workflow of a conventional three-step multi-station peripheral MRA protocol in comparison to the continuously moving table peripheral MRA protocol with syngo TimCT. While the multi-station protocol requires 12 steps to perform peripheral MRA, the continuously moving table protocol can be streamlined down to 6 steps.



[Figure 3] syngo TimCT FastView and planning of the TestBolus. The FastView sequence is based on a fast gradient echo sequence with fixed sequence parameters that runs without further sequence adjustments. The acquisition scan plane is transversal. Subsequent to data acquisition coronal and sagittal slices are automatically reformatted online. These reformats provide a gross overview of the patient's anatomy and serve as localizers to plan the transversal plane of the TestBolus sequence (yellow frame).

MRA with TimCT – How to set things to move

The TimCT protocol for performing peripheral MRA consists of 6 steps only (Fig. 2). Image planning on large FoV body localizers and vessel scouts streamlines the workflow, thus facilitating the setup of large FoV examinations. The TimCT peripheral MRA examination starts with the acquisition of a FastView localizer (step 1):

[1] syngo TimCT FastView

The FastView sequence is based on a fast 2D gradient echo sequence with fixed sequence parameters and runs without further sequence adjustments. The acquisition scan plane is transversal. The scanning range extends from the head region down to the feet with almost whole-body coverage. Subsequent to data acquisition, large field-of-view (FoV) coronal and sagittal slices are automatically reformatted and displayed online. These reformats provide a gross overview

of the patient's anatomy and serve as localizers to plan further examination steps (Fig. 3). Since the FastView sequence uses only low flip angles for spin excitation, this sequence is non-critical with regards to the specific absorption rate (SAR). While the FastView is being acquired, the MRI system automatically detects and displays individual RF coil positions of the Tim Matrix coils with regard to their location on the patient's body. Another feature is that FastView provides all relevant scanner adjustment parameters with feedback to the system while the scan is being acquired.

[2] TestBolus

Contrast bolus timing for peripheral MRA in the TimCT protocol is performed with the TestBolus sequence. This T1-weighted 2D fast gradient echo sequence provides one thick imaging slice that is oriented in the transversal plane and positioned

several centimeters above the renal arteries (Fig. 3). The TestBolus sequence provides one image per second and runs for 60 seconds. The sequence is started simultaneously with administration of a small contrast agent bolus (e.g. 2 ml). Signal enhancement in the aorta indicates arrival of the contrast bolus in the target vessel. With careful investigation of the TestBolus images, the time interval from contrast injection to contrast arrival in the target vessel can be determined. This contrast bolus travel time has to be considered for proper synchronization of the contrast injection with the breath-hold command for the patient, and with the initiation of data acquisition for the 3D FLASH TimCT MRA sequence.

[3] VesselScout

The VesselScout sequence provides a fast comprehensive large FoV overview of the target vessel tree. The VesselScout sequence is based on a fast rephased-dephased gradient echo sequence that generates two echoes per excitation to provide images where signal of static tissue is eliminated while signal from flowing blood is preserved. Planning of the multi-station VesselScout is performed in sagittal orientation on the previously acquired whole-body images provided by the FastView localizer (Fig. 4). Subsequent to data acquisition, the images of this multi-station sequence are composed online and provide a comprehensive large FoV overview of



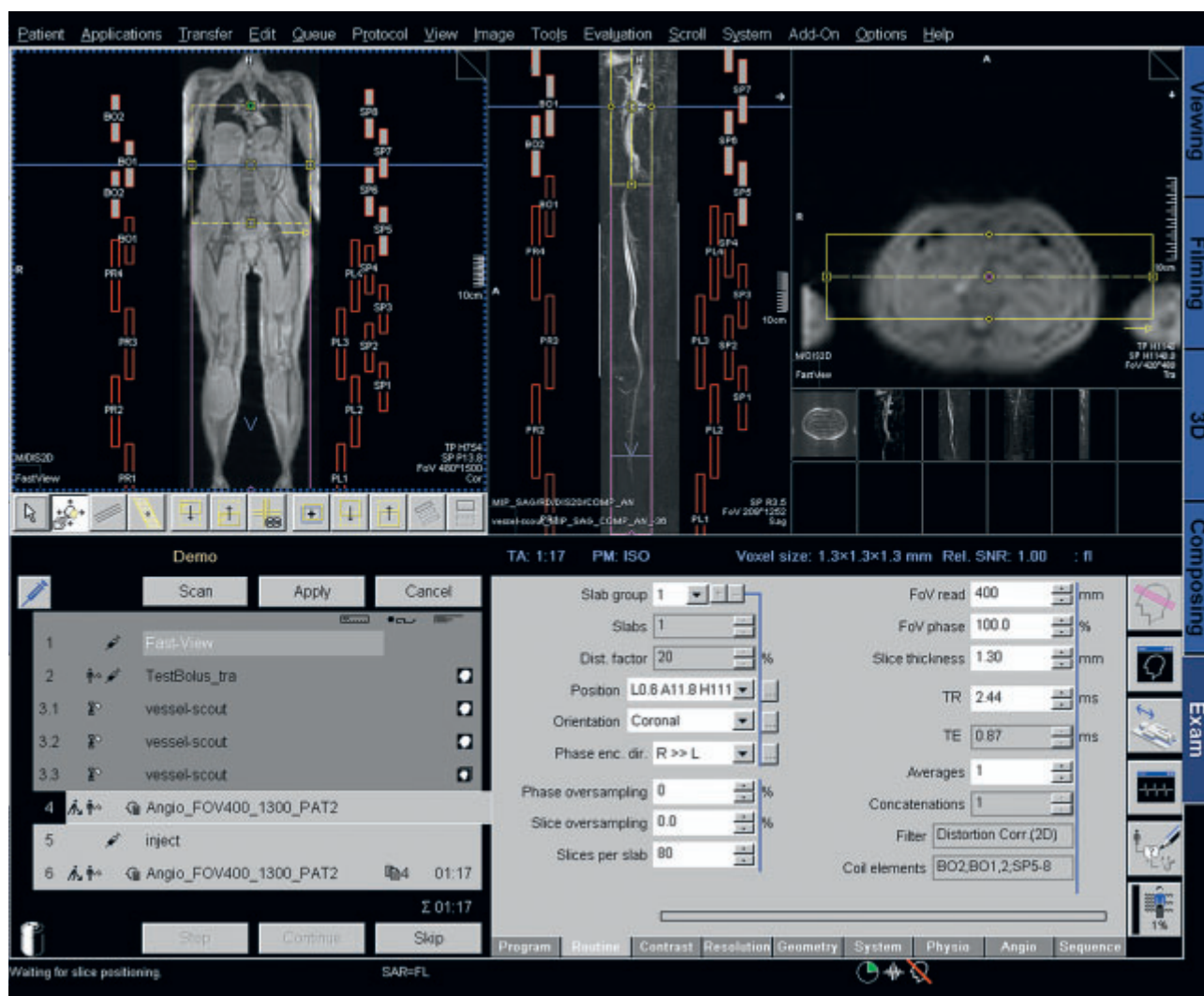
[Figure 4] syngo TimCT FastView and planning of the VesselScout. Here the whole-body localizers provided by the FastView sequence serve as a basis to plan the VesselScout sequence. This is a multi-station rephased-dephased localizer in sagittal orientation with inline composing. The rephased-dephased sequence eliminates signal from static tissue and preserves signal from flowing blood thus providing a fast sagittal overview of the entire vessel tree.

the larger peripheral arteries. This vessel localizer can then be used for further planning of the 3D MRA imaging volumes.

[4] syngo TimCT 3D MRA native

Planning of the 3D FLASH MRA imaging volume is performed in coronal orientation on the previously acquired whole-body localizer provided by the FastView sequence as well as on the large FoV target vessel localizer provided by the VesselScout sequence (Fig. 5). Since this is a continuously moving table protocol, the user only has to assure that the MRA volume covers the vessels of interest over the full lengths of the VesselScout and that the imaging range is covered with

surface RF coils. No further steps are required. The patient is instructed with a breathing command to inspire and to hold his breath at the beginning of the examination (abdominal region). The TimCT technology here provides data acquisition while the table with the patient is continuously moving through the isocenter of the magnet. During continuous table movement, the MRI scanner among the matrix of Tim RF coils automatically detects the receive coil elements that are inside of the isocenter at a time and “on-the-fly” switches off all coil elements outside of the isocenter. This effectively cuts down the number of active coil elements and thus reduces the amount of acquired data and avoids noise sam-



[Figure 5] VesselScout and planning of the syngo TimCT 3D FLASH MRA sequence. The coronal view of the FastView localizer and the sagittal view of the Vessel Scout together serve as reference for planning of the coronal slab of the 3D FLASH MRA sequence. Since this is a continuously moving table protocol, the user only has to assure that the MRA volume covers the vessels of interest over the full lengths of the VesselScout. No further planning steps are required.



[Figure 6] 3D coronal maximum intensity projection (MIP) of the peripheral MRA of a 30-year-old male healthy volunteer acquired with the continuously moving table technique syngo TimCT. The technique here provides a seamless large field-of-view (FoV) 3D MR angiogram covering the suprarenal aorta down to the peripheral arteries with high image quality.

pling of RF coils that do not contribute to the imaging signal. Immediately after finishing the data acquisition, online image reconstruction is being performed and seamless large-FoV native images of the 3D imaging volume are being displayed. These non-contrast native images are the basis for post-contrast image subtraction.

[5] Contrast injection

For the peripheral MRA TimCT protocol, contrast agent was administered with a biphasic contrast injection scheme using an automatic contrast injector. The first third of the volume was injected with a flow rate of 0.8 ml/sec. The remaining two thirds of the contrast volume were injected with a flow rate of 0.5 ml/sec followed by a saline flush of 20 ml at a flow rate of 1.0 ml/sec.*

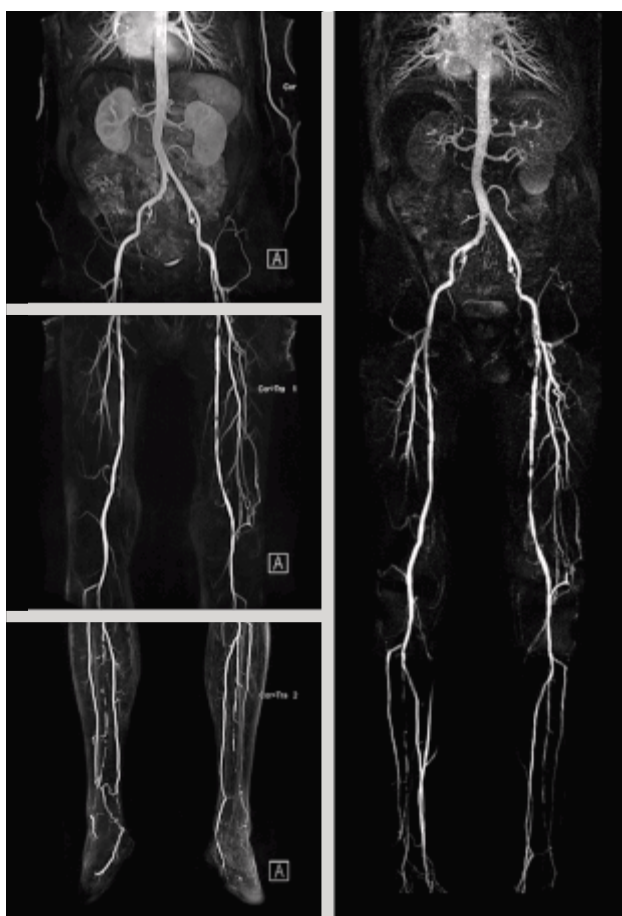
[6] 3D MRA contrast

Following contrast injection, in this last step of the TimCT angiographic examination of the peripheral arteries, the 3D FLASH MRA sequence with continuously moving table technique is rescanned with identical imaging parameters as described for the 3D FLASH native scan (see step 4). The patient again is instructed with a breathing command to hold his breath while the abdominal body region initially is in the isocenter. The patient table continuously moves through the isocenter of the magnet as the contrast-bolus travels continuously through the peripheral arteries of the patient. This finally results in a coronal oriented seamless large FoV 3D MRA data set covering the arterial contrast phase of the abdominal aorta from the renal arteries over the peripheral arteries down to the feet. The images of the previously acquired native 3D FLASH scan are automatically subtracted from the contrast images, resulting in angiographic images with subtracted background signal. The resulting background-subtracted source images are reconstructed as large FoV coronal displays of the target vessels that can be post-processed as comprehensive maximum intensity projections (MIP) displays of the complete vessel tree in a single step (Fig. 6). Imaging parameters for the large FoV peripheral MRA TimCT protocol were: 3D FLASH coronal, TR/TE 2.44/0.87 ms, flip angle 25°, bandwidth 1420 Hz/pixel, FoV 400 x 1300 mm, matrix 320 x 1380, slab width 115 mm. Parallel imaging with GRAPPA (acceleration factor of 2, 24 reference lines) resulted in a large FoV 3D MRA data set with an isotropic spatial resolution of 1.3 x 1.3 x 1.3 mm³ that was acquired within 77 seconds.

Moving patients with TimCT: First clinical experience

Direct comparison of conventional three-step multi-station peripheral MRA to the first clinical application of the continuously moving table syngo TimCT technique in patients with peripheral arterial occlusive disease (PAOD) revealed excellent image correlation of both techniques (Fig. 7). Both techniques provided comparable image quality. Image interpretation and vessel assessment on TimCT images was facilitated due to the lack of discontinuity artifacts. However, due to higher spatial resolution of the two lower stations using the

standard multi-station protocol, small intravascular arterial vessels appeared slightly crisper in this protocol. The time for data reconstruction was comparable for both protocols (2 min). From a user's point of view, the streamlined workflow of the TimCT protocol considerably facilitated planning of the large FoV 3D MRA data slab that in the TimCT protocol is performed straightforward on two comprehensive data sets (FastView and VesselScout) while three individual 3D image slabs have to be positioned and oriented in the conventional multi-station protocol.



[Figure 7] 3D coronal maximum intensity projections (MIP) of the peripheral conventional three-step multi-station MRA protocol in comparison to the continuously moving table protocol with syngo TimCT acquired on a 60-year-old male patient with peripheral arterial occlusive disease (PAOD). Note that the multi-station protocol acquires multiple slightly overlapping fields-of-view (FoV) while the continuously moving table protocol provides one seamless large FoV with full anatomic coverage that is not hampered by any discontinuity artifacts.



[Figure 8] Continuously acquired 3D MRA of the peripheral vasculature in a 63-year-old male patient with peripheral arterial occlusive disease (PAOD) (Rutherford grade II Category 4). Note multiple stenoses and occlusions (arrows), especially in the pelvic and upper leg region.

Conclusion

The *syngo* TimCT technique provides high-quality seamless large field-of-view MR images for virtually all imaging applications that exceed the constraints of conventional FoVs. In contrast to multi-station techniques, boundary artifacts that might appear at the edges between two adjacent FoVs are completely eliminated. The technique significantly reduces the number of examination steps thus streamlining the workflow to perform comprehensive large FoV examinations. Peripheral MRA – as demonstrated here – is the first among a large palette of other MR imaging applications that exceed the constraints of conventional FoVs. Further extension to whole-body MRA as well as whole-body metastasis screening and staging in oncologic patients will potentially benefit from the *syngo* TimCT technique as well. The TimCT technique furthermore holds potential for further expanding the role of open short-bore MRI systems – like the MAGNETOM Espree – that inherently provide limited FoVs in the longitudinal direction. Get ready to move!

*Works In Progress – The information about this product is preliminary. The product is under development. It is not commercially available in the US and its future availability cannot be assured.

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